Replacement Fuel Goal
HFCIT Input

Strategy
To realize the vision of the President's Hydrogen Fuel Initiative, in which the first car driven by a child born in 2003 could be powered by hydrogen and pollution free, the Hydrogen Program will support RD&D of transportation, stationary, and portable hydrogen fuel cell technologies in parallel with technologies for the hydrogen production and delivery infrastructure. The current focus is on addressing key technical challenges (for fuel cells and hydrogen production, delivery, and storage) and institutional barriers (such as hydrogen codes and standards to maximize safety, and training and public awareness). Once technical and cost targets are close to being met and the business case is established, policies and programs with market or endorser incentives may be warranted to facilitate the transition. The Program is partnering with automotive and energy companies to make the technology ready by 2015, thereby enabling the availability of safe, affordable, and viable hydrogen fuel cell vehicles and hydrogen fuel infrastructure to consumers by 2020.

The Hydrogen Program is currently conducting basic and applied research, technology development and learning demonstrations, underlying safety research, systems analysis, and public outreach and education activities. These activities include cost-shared, public-private partnerships to address the high-risk, critical technology barriers preventing widespread use of hydrogen as an energy carrier. Public and private partners include automotive and power equipment manufacturers, energy and chemical companies, electric and natural gas utilities, building designers, standards development organizations, other federal agencies, state government agencies, universities, national laboratories and other national and international stakeholder organizations. The Hydrogen Program encourages the formation of collaborative partnerships to conduct RD&D and other activities that support program goals.

These activities address the development of hydrogen energy systems for transportation, stationary power, and portable power applications. Transportation applications include fuel cell vehicles and hydrogen refueling infrastructure. Stationary power applications include use of hydrogen for backup emergency power and residential electric power generation. Portable power applications include consumer electronics such as cellular phones, hand-held computers, radios, and laptop computers. DOE is funding RD&D efforts that will provide the basis for the near-, mid-, and long-term production, delivery, storage, and use of hydrogen derived from diverse energy sources, including fossil fuel, nuclear energy, and renewable sources. Distributed reforming of natural gas and renewable liquid fuels (e.g., ethanol and methanol) is likely to be the most efficient and economical way to produce hydrogen in the transition to the hydrogen economy, but costs are still too high.

Key hurdles
The key technical hurdles of cost, performance, and safety, must be overcome in each area to achieve the hydrogen economy. These hurdles include the following:

PRODUCTION
- Low cost hydrogen production techniques
- Low cost and environmentally sound carbon capture and sequestration technologies
- Advanced hydrogen production techniques from fossil, renewable, and nuclear resources

DELIVERY
- Lower-cost hydrogen transport technology
- Appropriate, uniform codes and standards
- Right-of-way for new delivery systems
- High investment risk of developing hydrogen delivery infrastructure

STORAGE
- Low cost, high capacity, lightweight, and low volume hydrogen storage systems

CONVERSION (FUEL CELLS)
- Low cost, durable, and reliable fuel cells that can be mass produced

TECHNOLOGY VALIDATION
- Successful field tests and demonstrations of integrated systems that meet customer requirements
- Supportive public policies to stimulate infrastructure and market readiness

SAFETY, CODES and STANDARDS
- Fuel gas code that includes hydrogen
- Uniform safety standards for certification of fuel cell vehicles, stationary power facilities, and portable devices

EDUCATION
- Widespread understanding of, and confidence in, the safe use of hydrogen as an energy carrier
- Access to accurate, objective information about the hydrogen economy and hydrogen fuel cell technology
- Education and training for emergency responders and code officials

To achieve the hydrogen economy, a combination of technological breakthroughs, market acceptance and large investments in a national energy infrastructure will be required. The process will take decades and require an evolutionary process that phases hydrogen in as the technologies and their markets are ready. DOE is funding RD&D efforts that will provide the basis for the near-, mid-, and long-term production, delivery, storage and use of hydrogen derived from diverse energy sources, including fossil fuel, nuclear energy, and renewable sources.

The Hydrogen Fuel Initiative Budget Request for FY2007 in the following table breaks out the programs areas.

	FY 2004 Appropriation[2] ($000)	FY 2005 Appropriation[3] ($000)	FY 2006 Enacted[4] ($000)	FY 2007 Request[5] ($000)
Basic Research	$0	$29,183	$32,500	$50,000
Production and Delivery	$19,163	$31,503	$49,947	$79,120
Storage	$13,628	$22,418	$26,600	$34,620
Conversion (Fuel Cells)	$53,954	$55,759	$34,254	$57,075
Technology Validation	$15,648	$26,098	$33,594	$39,566
Manufacturing R&D	$0	$0	$0	$1,978
Safety, Codes and Standards[6]	$6,310	$6,350	$6,138	$15,268
Education	$2,417	$0	$495	$1,978
Systems Analysis	$1,429	$3,157	$4,925	$9,892
Earmarks (Congressionally Directed Funds)	$43,967	$47,236	$47,470	$0
TOTAL	$156,516	$221,704	$235,923	$289,497

Program Activities and Highlights

The following sections provide an overview of key ongoing and planned hydrogen activities in basic research, production, delivery, storage, conversion (fuel cells), technology validation, safety, codes and standards, education, and systems analysis and integration. Out-year planning may identify needs for additional RD&D to support and expand this portfolio of activities.

Hydrogen Production

Lowering hydrogen production cost is a top priority. The National Academies' study requested by DOE and completed in 2004 provides insight into a hydrogen feedstock strategy for the transition and long term. The study has helped DOE set priorities for hydrogen production research needs. Ongoing and planned activities include the following:

- Conduct research to develop small-scale, distributed natural gas, liquid reformer, and electrolysis technologies (needed for the transition) that can operate reliably, safely, and cost-effectively in a typical fueling station using various feedstocks including natural gas, coal-derived carriers, or renewable liquids such as ethanol or other sugar derivatives. R&D activities include:
  - Electrolysis technologies with reduced capital costs, enhanced system efficiency, and improved durability for distributed scale hydrogen production from renewable-sourced electricity and water
  - Lower-cost membranes and catalysts that can operate at higher temperatures and pressures, as well as improved system integration to lower the cost of manufacturing
- Conduct research to develop large-scale, centralized, efficient hydrogen production from coal with carbon sequestration, including:

    - Computational methods and advanced technologies to reform high hydrogen content coal-derived carriers
    - Advanced water-gas shift, separation, cleanup, and process intensification technologies to produce lower- cost hydrogen
    - Technologies to integrate carbon sequestration (capture and containment) with fossil-based production systems
    - Multi-fueled, oxygen-blown gasification system for co-producing hydrogen and electric power
- Accelerate and expand research on the lowcost production of hydrogen from renewable resources, including:
    - Component development and systems integration efforts that will enable electrolyzers to operate from inherently intermittent and variable-quality power derived from wind and solar sources
    - Solar-driven high-temperature chemical cycle water splitting
    - Photoelectrochemical systems
    - Thermochemical conversion of biomass
    - Photolytic and fermentative microorganism systems
- Accelerate and expand research on centralized, low cost production of hydrogen using nuclear energy, including high-temperature electrolysis and sulfur-based thermochemical cycles. This activity could lead to the construction of an advanced nuclear demonstration plant with electricity and hydrogen co-production capabilities.
    - Improved reformer technologies using partial oxidation (or autothermal reforming) and steam reforming processes achieving higher energy efficiency and lower capital cost

- Conduct supporting basic research for hydrogen production to enable breakthroughs in catalysis, separations, and fundamental processes including:
    - Design of catalysts at the nanoscale with the main emphasis on nanoscale phenomena; innovative synthesis and screening techniques; novel characterization techniques; and theory, modeling, and simulation of catalytic pathways
    - Improved understanding of lightinduced dynamic processes in molecules, polymers, and semiconductor nanoparticles to support the development of low-cost solar cells and photocatalysts
    - Investigation of new semiconductors, polymers, supramolecular assemblies, and catalysts (including biological or bioinspired materials) to enable the synthesis of two- and three-dimensional chemical systems for efficient light harvesting, charge separation, and fuel formation
    - Improved understanding of the pathways by which hydrogen is made and processed in living organisms to enable breakthroughs in feasible photobiological and biological reactor technologies
- Investigation of membrane materials for separation, purification, and ion transport including integrated nanoscale architectures; fuel cell membranes; and theory, modeling, and simulation of separation processes and mechanisms

Hydrogen Delivery

Delivery technologies and economics will heavily influence the level of infrastructure investment and safety assurance required. New concepts will be needed to reduce delivery costs from the point of hydrogen production to the point of use at refueling stations and distributed power facilities. Systems analysis of delivery alternatives will show the lifecycle cost advantages and disadvantages of the alternative approaches for transporting hydrogen over long distances and will identify areas in which R&D could provide the greatest cost reductions and the greatest value. Ongoing and planned R&D activities include the following:

- Conduct research to lower the cost of the hydrogen delivery infrastructure, including the development of:
  - More reliable lower-cost compression technology
  - More energy efficient and lower cost liquefaction technology
  - Improved pipeline materials to resolve hydrogen embrittlement
  - New liquid or solid hydrogen carriers (e.g., metal or chemical hydrides, carbon-based materials, etc.) that can increase the energy density of hydrogen transport
- In coordination with the DOT, develop technologies (e.g., seals, valves, sensors and controls) to ensure the safety of the hydrogen delivery system.
- Supporting basic research needs include:
  - Improved understanding of how hydrogen reacts and interacts with the surface, interface, grain boundaries, and bulk defects of particular materials to clarify the mechanisms of hydrogen embrittlement and help guide proper selection of existing materials or discovery/design of suitable new materials (e.g., nanostructured composites, advanced polymers)
  - Design/development of novel new materials for off-board (bulk) hydrogen storage or as hydrogen carriers

Hydrogen Storage

Lower-cost, lighter-weight, and higher-density hydrogen storage is one of the key technologies needed for the hydrogen economy. Advanced storage materials that show promise include complex metal hydrides, chemical hydrides, carbon structures, and metal organic frameworks. Understanding how to produce and contain these advanced materials will be required as well as how to fill and discharge hydrogen, manage pressure and thermal properties, and integrate the materials into practical systems for stationary and mobile applications. The DOE's "Grand Challenge" solicitation for Hydrogen Storage formed the basis for the National Hydrogen Storage Project, which involves approximately 40 universities, 15 companies and 10 federal laboratories in conducting R&D to address these challenges. Ongoing and planned hydrogen storage R&D includes the following activities:

- Complete research, including materials work, to validate high-pressure and cryogenic tanks as near-term approaches
- Develop and evaluate innovative storage approaches including reversible storage materials, such as carbon nanotubes and metal hydrides, regeneration issues related to chemical hydrides, and other novel materials and concepts
- Downselect carbon nanotube technology based on material capacity of six wt % hydrogen

- Conduct collaborative research on complex metal hydrides, chemical hydrides, and carbon-based materials at the Centers of Excellence through the National Hydrogen Storage Project
- Conduct basic research, with an emphasis on understanding the chemical and physical processes governing materials-hydrogen interactions to enable the design and discovery of new, higher-capacity hydrogen storage materials, including:
- Investigation of new properties and capabilities offered by nanostructures to further enhance storage capacity and to improve uptake/release kinetics
- Design of two- and three-dimensional nanoarchitectures to improve the capabilities of today's metal and complex hydrides
  - Theory, modeling, and simulation approaches
  - Novel analytical and characterization tools

Conversion (Fuel Cells)

Reducing fuel cell cost (by a factor of approximately 4) and improving durability and reliability will be required to ensure the commercial viability of fuel cells in both mobile and stationary applications. Fuel cell research will continue on high-efficiency polymer electrolyte membranes (PEM) and other stack components and systems to meet cost, durability, power density, heat utilization, cycling, load-following, operation and start-up in cold weather, and other key performance targets. In 2004, DOE conducted a go/no-go review of on-board fuel processing activities. The review resulted in a no-go decision, concluding that on-board fuel processing would not improve sufficiently from its current status to compete effectively with gasoline hybrid vehicles or to support transition to a hydrogen economy. Projects that focus on on-board fuel processing have therefore been terminated or redirected to support development of fuel processors for stationary applications or development of catalysts suitable for a variety of fuel processing applications (e.g., auxiliary power units). Ongoing and planned fuel cell R&D includes the following activities:

- Focus on overcoming critical technical hurdles at the component level to improve overall polymer electrolyte membrane fuel cell performance and durability while lowering costs, including:
  - Proton-conducting membranes that operate at 120ºC for transportation applications and 150ºC for stationary applications
  - Membranes that can operate at low relative humidity
  - Cathodes with decreased precious metal loading
  - Non-precious metal cathode catalysts
  - Bipolar plate materials and coatings with improved corrosion resistance
- Continue the development of auxiliary power unit systems for heavy vehicle application and the feasibility assessment of fuel cells for portable power applications
- Evaluate the impact of hydrogen quality (i.e., tolerance to impurities) on fuel cell performance and durability
- Independently review the status of progress toward critical targets, such as cost
- Conduct research to address technology shortfalls associated with cold weather start-up and operations
- Conduct basic research to:

- o Better characterize the mechanisms of ionic (including protonic) transport in fuel cell materials (including dependence on relative humidity, temperature, acidity, etc.)
- o Improve understanding of the relationship between precious metal catalytic behavior (catalytic activity, selectivity, deactivation, etc.) and catalyst composition, crystal structure, and morphology to guide design of new, non-precious metal catalysts
- o Improve understanding and ability to control the electrochemical processes at the electrodes and membrane electrolyte interfaces

Technology Validation

Efforts are needed to demonstrate hydrogen energy systems (including fuel cells, engines, and turbines) in mobile and stationary applications.

Learning demonstrations provide technical data on operation in a real world environment to measure progress and to help guide the research program as well as financial data for determining market and investment risks. The National Hydrogen Learning Demonstration Project will support a statistically significant number of hydrogen vehicle and refueling station demonstrations in several locations in order to:

- Validate technology status and develop data to guide R&D addressing:
  - o Hydrogen fueling station safety, operations, reliability, vehicle fueling interface, hydrogen production efficiency, and cost
  - o Vehicle performance and reliability under real operating and climate conditions
- Validate safety and performance data from power park systems to co-produce hydrogen and electricity for vehicles and grid, respectively

Key Milestones

Key milestones and accomplishments need to be achieved to overcome the aforementioned hurdles. The key program technical milestones for achieving a hydrogen economy include the following:

- Hydrogen produced from diverse, domestic resources at \$2.00-\$3.00 per gallon of gasoline equivalent (delivered, untaxed)
- On-board hydrogen storage systems with improved capacity to enable a driving range greater than 300 miles for most light-duty vehicles.
- Polymer electrolyte-membrane (PEM) automotive fuel cells that cost \$30-\$45 per kilowatt and deliver 5,000 hours of service (service life of vehicle).

The milestone chart shown in the following table presents the key activities of the Hydrogen Program through completion of the critical path technology development phase in 2015.

Production Milestones[b]

Distributed Natural Gas/Renewable Liquid Fuels

1. 2010: Develop technology to produce hydrogen from natural gas at a refueling station that projects to a cost of \$2.50/gge for hydrogen. [At the pump, untaxed, no carbon sequestration, at 5,000 psig]

2. 2015: Develop technology to produce distributed hydrogen from renewable liquid fuels at a refueling station that projects to a cost of \$2.50/gge for hydrogen. [At the pump, untaxed]

Central Coal[c, d]

3. 2010 → 2011: Develop pre-engineering membrane separation modules and reactors for hydrogen production that meet membrane cost target of \$150-200/ft^2

4. 2015: Demonstrate a near-zero atmospheric emission coal plant producing hydrogen and power with carbon capture and sequestration at a 25% cost reduction that projects to \$0.80/gge at the plant gate (ultimate target: \$1.80/gge delivered)

Renewable Resources[e]

5. 2010: Develop technologies for integrated distributed wind hydrogen production at \$2.85/gge delivered assuming a 1,500 gge/day electrolyzer system and \$0.04/kWh wind electricity (2015: \$1.75/gge from centralized wind electrolysis at \$0.03/kWh; ultimate target: \$2.75/gge delivered)

6. 2015 → 2018: Demonstrate laboratory-scale photobiological water splitting system to produce hydrogen at an energy efficiency of 5% (solar-to-hydrogen). Demonstrate laboratory-scale photoelectrochemical water splitting system to produce hydrogen at an energy efficiency of 10% (solar-to-hydrogen)

High-Temperature Thermochemical[f]

7. 2007 → 2008: Operate laboratory-scale thermochemical and electrolytic processes to determine the feasibility of coupling them with a nuclear reactor

8. 2010 → 2012: Laboratory-scale demonstration of solar-driven high-temperature thermochemical hydrogen production that projects to a cost \$6.00/gge (ultimate target: \$7.00/gge delivered)

9. 2011 → 2014: Pilot-scale demonstration of thermochemical hydrogen production system for use with nuclear reactors that projects to a cost of \$2.50/gge (ultimate target: \$3.50/gge delivered)

10. 2017 → 2020: Engineering-scale demonstration of thermochemical hydrogen production system for use with nuclear reactors that projects to a cost less than \$2.00/gge (\$3.00/gge delivered)

Storage Milestones

1. 2007: Downselect hydrogen storage options with potential to meet 2010 targets

2. 2010: Develop and verify on-board storage systems achieving: 6% by weight capacity and 1,500 watt hours/liter energy density at a cost of \$4.00/kWh of stored energy

3. 2015: Develop and verify on-board storage systems achieving: 9% by weight capacity, 2,700 watt hours/ liter, and \$2.00/kWh

Validation Milestones

1. 2008: Validate stationary fuel cell system that co-produces hydrogen and electricity at 20,000 hours durability with 32% efficiency at a cost of \$1500/kW or less

2. 2009: Validate polymer electrolyte membrane fuel cell vehicles at multiple sites, achieving 2,000 hours durability, a 250-mile range, and \$3.00/gge of hydrogen

3. 2013: Validate stationary fuel cell system that co-produces hydrogen and electricity at 40,000 hours durability with 40% efficiency at a cost of \$750/kW or less

4. 2014: Validate PEM fuel cells on operational vehicles in different climatic conditions that can be produced for \$45/kW when produced in quantities of 500,000

5. 2015: Validate polymer electrolyte membrane fuel cell vehicles achieving 5,000 hours durability (service life of vehicle) and a 300-mile range

Conversion Milestones[e]

1. 2004: Decision to discontinue on-board fuel processing based on inability to achieve 78% efficiency and <0.5 minute start time

2. 2010 → 2011: Distributed stationary generation natural gas/propane 5-250 kW fuel cell go/no-go decision based on ability to achieve: 40% electrical efficiency, 40,000 hours durability (equivalent to service life between major overhauls), at a cost of less than \$400-\$750/kW (depending on application)

3. 2010: Develop direct hydrogen polymer electrolyte membrane automotive fuel cell operating at 60% peak efficiency, 220 W/L density, 325 W/kg specific power at a cost of \$45/kW (automotive production quantity)

4. 2015: Polymer electrolyte membrane automotive fuel cell meets cost of \$30/kW

5. 2015: Fuel cell/turbine hybrid operating on coal developed at a cost of \$400/kW with a HHV efficiency of 50% with carbon sequestration

Education, Safety, and Codes and Standards Milestones[e]

1. 2006 → 2007: Facilitate publishing domestic and international hydrogen quality standards and publish initial set of basic safety training materials

2. 2007 → 2008: Publish initial Best Practices manual for hydrogen safety

3. 2007 → 2009: Education program for safety and code officials in place

4. 2010 → 2012: Initial set of technical codes and standards in place to support demonstrations, commercialization decisions and regulatory standards

♦ Phase 1 Technology Readiness: 2015

Based on technology development success in meeting customer requirements and establishing a business case

Centralized Delivery Milestones[e]

1. 2007: Define the criteria for a cost-effective hydrogen fuel delivery infrastructure for supporting the introduction and long-term use of hydrogen for transportation and stationary power

2. 2010 → 2012: Develop technologies to reduce the cost of hydrogen fuel delivery from the point of production to the point of use in vehicles or stationary power units to <\$1.70/gge of hydrogen

3. 2015 → 2017: Develop technologies to reduce the cost of hydrogen fuel delivery from the point of production to the point of use in vehicles or stationary power units to <\$1.00/gge of hydrogen

Systems Analysis Milestones[e]

1. 2007: Develop transition scenarios for infrastructure and hydrogen resources for a hydrogen economy

2. 2008: Develop a macro-system model of the hydrogen fuel infrastructure to support the transportation system

3. 2009 → 2010: Complete assessment of hydrogen quality requirements for production, delivery, storage and fuel cell pathway

4. 2010 → 2011: Develop electricity infrastructure module for the macro-system model

NEXT STEPS

- Assess, through independent review, the status of three major technical milestones:
  - In hydrogen storage, determine the potential of cryogenic-compressed hydrogen tanks to meet DOE's 2010 targets

- Verify the 2005 modeled cost of $110/kW for 80-kW transportation fuel cell systems (based on 500,000 units/year) (The 2006 and 2010 DOE targets are $110 and $45 per kilowatt, respectively)
- In hydrogen production, determine if laboratory research is complete for distributed natural gas reforming to achieve $3.00 per gallon gasoline equivalent (this technology will need to be validated later at full-scale)

 Continue to coordinate the detailed multi-year RD&D plans and priorities for hydrogen and related technology development efforts within DOE and
DOT to make them consistent with this planning document, the Energy
Policy Act of 2005, and the recommendations of the National Academies' studies of the Hydrogen Economy and the FreedomCAR and Fuel Partnership.
 Strengthen coordination by continuing to utilize the Hydrogen Program
Coordination Group composed of representatives from the DOE Offices of
EE, FE, NE, SC, PI, and CFO, and the Department of Transportation.
 Complete and publish the DOE Hydrogen Program Safety Plan, the DOE
Hydrogen Program Risk Management Plan, and the Systems Analysis Plan.
 Promote the sharing of safety-related information and maintain a database of safety "learnings."
 Conduct the third annual DOE Hydrogen Program Merit Review and Peer Evaluation.
 Select members for and convene the HTAC.
 Reflect the importance of the following activities in the Department's outyear planning and budgeting:

- Basic and applied research in hydrogen storage, production and delivery, and fuel cell cost and durability
- Hydrogen delivery and analysis of infrastructure development (these activities will be closely coordinated with the DOT, which is responsible for efforts to ensure the safety of the hydrogen delivery system)
- Economic and systems analyses for determining and mitigating investment risks associated with hydrogen infrastructure and related technologies (e.g., fuel cell systems engineering and manufacturing plants)
- Education activities focused on the key target audiences directly involved in near-term hydrogen demonstration

 Strengthen existing interagency coordination efforts to ensure that Federal investments in hydrogen and fuel cell technology development are leveraged to the maximum extent. The Interagency Hydrogen and Fuel Cell Technical Task Force, in accordance with the Energy Policy Act of 2005, will work toward a safe, economical, and environmentally sound hydrogen fuel infrastructure by coordinating the efforts of the Office of Science and Technology Policy; the Departments of Energy, Transportation, Defense, Commerce, and Agriculture; the Office of Management and Budget; National Science Foundation; Environmental Protection Agency; National Aeronautics and Space Administration; and other agencies as appropriate. In 2005, the task force created a website at www.hydrogen.gov to provide information on all Federal hydrogen and fuel cell activities.
 Increase awareness of the nation's regulatory framework of energy, economic, and environmental policies at the federal, state, and local levels, and work with the

appropriate agencies to coordinate the timing of policy instruments and regulatory actions to allow technology to meet market requirements.

- Continue DOT and DOE participation in the development of Global Technical Regulations for fuel cell light duty vehicles.
- Identify opportunities to work more closely with emerging state-led initiatives to advance the hydrogen economy.
- Strengthen international cooperation on hydrogen-related research, development, and demonstration programs and on the development of interoperable codes and standards through the International Partnership for the Hydrogen Economy.
- Implement the requirements and recommendations of the Energy Policy Act of 2005 (see box in Executive Summary), subject to congressional appropriations.

In summary, a great deal of progress has been made since 2003 in planning and carrying out the research, development, and demonstrations. The Department of Energy expects significant results to be achieved through the President's Hydrogen Fuel Initiative in FY 2006 and beyond.

SCENARIOS

The results of the GPRA 07 base case and the high fuel price sensitivity analyses were used to describe the benefits of the Hydrogen Program. These analyses contain the program's expectations for technology improvements to achieve technology goals and milestones.

For the purposes of the ascribed Goal Analysis, the benefits results of the GPRA07 base case were used for the Goal Analysis Medium case. In the GPRA analysis, the AEO2005 reference case oil prices were employed in the benefits analysis. The benefits for the medium case are provided in the following table:

Benefits	**2020**	**2025**	**2030**
Environmental			
Carbon Savings (millions metric tons carbon equivalent/yr)	0	4	13
Security			
Oil Savings (millions barrels per day)	0.03	0.11	0.32
Vehicle Penetration (% of stock)	0	1	2
Prices			
World Oil price, $2003/bbl	28.50	30.31	32.00

For the Goal Analysis High case, the results of the high fuels prices sensitivity for the GPRA07 analysis were used. The benefits for this High case are provided in the following table:

Benefits	**2020**	**2025**	**2030**
Environmental			
Carbon Savings (millions metric tons carbon equivalent/yr)	0	7.0	19.0
Security			
Oil Savings (millions barrels per day)	0	0.16	0.47
Vehicle Penetration (% of stock)	0	2	4
Prices			
World Oil price, \$2003/bbl	44.33	48.00	52.00